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Variety Management in Manufacturing. Proceedings of the 47th CIRP Conference on Manufacturing Systems

## Using the TRL-methodology to design supporting ICT-tools for production operators

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### Abstract

The Technology Readiness Level or TRL, has a long history at NASA and American Department of Defence (DoD), when designing and testing new technologies. Could this methodology be used in a production system context? Due to the increased information complexity in production systems today new technologies and prototypes have to be developed and tested more frequently. Cognitive automation strategies are becoming a competitive benefit for the companies that have a standardisation when it comes to prototyping and testing. The aim of this paper is to show how the TRL could be used to design supporting ICT-tools for operators in Swedish production. The internal testing has been done at the university lab, and the external tests have been done in two industrial case studies as an input for the results in this paper. Results show that even though it is good to have a structured methodology to follow, it is difficult to put the methodology to use in a different context.

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**Keywords:** ICT, operators, production, cognitive automation, variety, strategy, manage, TRL

### 1. Introduction

In 1993, Pine wrote that Mass customization has been the mantra for today's manufacturing [1]. Today, almost twenty years later Mass customization still is the leading paradigm in production systems development. This generates a complexity, not only in the product itself but on manufacturing processes as well as company structures [2]. Increasing complexity continues to be one of the biggest challenges facing manufacturing today [3]. In order to handle this in production, smarter and personalized tools for information and communication are needed. To be able to have a strategy and to develop such tools in an effective way, methods for product development is needed.

The Technology Readiness Level (TRL) is used in Technology Readiness Assessment methods (TRA) [4] as a measure when implementing and designing and developing

new technology. Earlier research shows that industries often use informal and unstructured ways when developing and choosing Information and Communication Technologies (ICT) tools (or cognitive automation) for production operators [5, 6]. To solve this, structural methodologies and assessment methods are needed;

*To be most effective, the overall R&D organization (and its customers) should seek to conduct more or less formal TRAs, employing the TRLs, and not just individual managers evaluating their own options [4].*

This paper discusses how influences from the TRL and TRA could be used in a production context in order to develop ICT-tools for production operators. Further, this paper will show a developed methodology and two industrial cases showing how it has been used.

The main questions are whether the industry is ready for technology to be developed and integrated in the systems and

if the commercial technology could be adapted to the needs of the industry environment and the operator's needs?

## 2. Technology Readiness Level (TRL)

Technology Readiness Assessment (TRA) points when an organization attempts to determine the maturity of a new technology and/or capability (including required levels of engineering or economics-related performance) [4].

Technology Readiness Levels (TRLs) could then be described as the measurement of this assessment, TRL could be defined as:

*A systematic metric/measurement system that supports assessments of the maturity of a particular technology and the consistent comparison of maturity between different types of technology*

The methodology was supposed to provide a more precise means of describing the depth to which a research and technology program is to be pursued [10]. In close co-operation within NASA, United States Air Force and the Department of Defence the levels was refined and generalised. TRL definitions is now used by the U.S. Department of Defence are the most generic and best suited for adaptation by other fields of study.

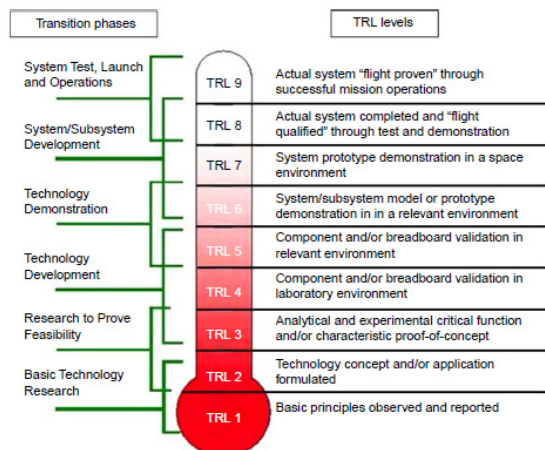


Fig. 1 The TRLs, Adapted from [7]

The TRL has been used in the manufacturing context in order to decide what technology to use and whether it is ready for the industry [8-11]. They have also shown that there can be disadvantages to just take the methodology and apply it in another context.

- The TRL evaluation process can be quite complex and time consuming, if done by the book, as more than 250 questions have been designed to assess the readiness level reached by a technology [7].
- The difficulties in applying TRLs to assess the readiness of software-based technologies and products [11, 12]

The advantage is the original usage that NASA had to create a common view of a technology's status in the design development phases and to create a structure when designing prototypes.

## 3. Product Development Process (PDP)

The methodology has been developed in cooperation with seven companies from four different types of industry i.e. Mining industry (2), Automotive (2), Engineering work-shop (2) and Medical equipment (1). The aim with the development is to design and test prototypes in real environment based on the company's needs in a structured way. The methodology is divided into 3 phases:

- Current state analysis
- Toolbox design
- Prototype development

The following sections will describe the methods used in each phase in order to collect data and information.

### 3.1. Current situation analysis

The first step in the methodology is to perform a current state analysis. This includes collecting data and information within four areas connected to the use of ICT;

- Task and needs
- Problems (triggers for change)
- Environment (company culture)
- Operator Role (Role allotment)

*Tasks and needs* – The companies have chosen an area or scenario that needs to be improved in terms of information and communication to and from the operators, methods used is observations and interviews.

*Problems* – In the selected area problems or triggers for changing the system [13] is collected through collecting statistics in the IT-system and through interviews involved personnel in the area.

*Environment* – What kind of culture has the company in terms of communication and information channels and top-down or bottom-up approach? Methods used are interviews and observations

*Operation role (role allotment)* – The information is collected in order to investigate the empowerment of the operators i.e. how many of tasks are performed by operators, e.g. what are their handling space in their daily work? [14]. A concept model to evaluate role allotment was used to evaluate how much control the operator has work [15, 16]. The model is a combination of Sheridan's five operator roles [17]: Plan, Teach (programming), Perform, Intervene, and Learn and work tasks in an automatic assembly system (presented in [18]). The input to the concept model was based on interviews where the concept model (based out of 17 points) is the basis for the interview. The output was divided into three categories: operators only, partly operators and others [19, 20]. Table 1 show results from two of the companies. An interesting result is that Case B defines them as an empowered organisation, but at the same time the operators only do 25 % of the tasks themselves. In order to develop the right support it is important to know the role allotment, if the operator have a large action space, they might need more complex support tool that can handle many different tasks. This result also implicates if the company is ready to invest in new technology.

Table 1. Current state analysis

Case	Scenario	Needs	Problems	Environment	Role Allotment
Case A Engineering work shop	Machining	- Improve work instructions - Share expert knowledge - Decrease paper handling	- Information transferring between shifts	Open and flat organization.	Operators only: 41 % Partly operators: 29 % Others: 29 %
Case B Engineering work shop	Heat treatment	- Improve work instructions - Share expert knowledge - Maintenance check-list	- Skilled and experienced resources as information sources. - Unstructured information	Define themselves as an empowered organization	Operators only: 25 % Partly operators: 35 % Others: 41 %

The second step is to filter and refining the four areas with help of scenarios of the specific problem area, contexts descriptions and by forming personas that will use the tools (this with help of the operator roles, company culture, technology use, and maturity of using new technology [10, 21], both as company and operators, competences among operators [22]).

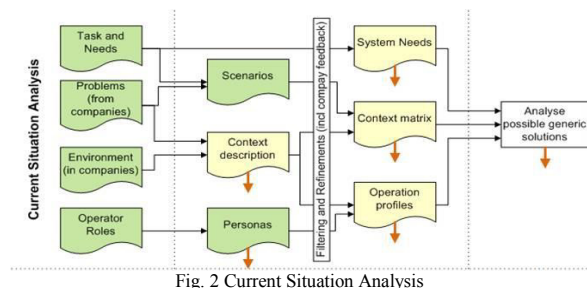


Fig. 2 Current Situation Analysis

The current state could be compared to TRL = 1 and 2 in terms of investigating state of the art within the area and translates the research questions into applied research and development were basic principles are observed.

### 3.2. Toolbox design

When the current state is assessed at all participating companies (or at all parts of the system if it is an internal investigation) the toolbox design starts. In this step generic tools and design guidelines are developed due to the result and collected information in the current state. A number of 'tools' or technical solutions are weighted and collected for further testing and design. Feedback from the prototype development also contributes to the further development of the tools and guidelines.

In order to know what type of tool to design, 'information technologies' in our context is divided into three different types of ways of presenting information; information carriers, information content and information structure [23], this is done in the second step of the methodology, *Toolbox Design*, were the information from the current state is used in order to choose the right information carrier and content.

The toolbox design could be compared to TRL<sub>2</sub>, the invention of solutions begins and practical application could be invented. One thing that differs is that at TRL<sub>2</sub> the applications are speculative, and there may be no proof or detailed analysis to support the assumptions [2]. The data that supports the

assumptions in the PDP methodology is weighting based on needs, if the needs were simulate thru company roles or companies, they were sorted into themes.

### 3.3. Prototype development

In the prototype development phase, the tools are tested according to the design guidelines. The tools are tested one by one or many together depending on the company needs. The evaluation is done in four different ways: internal review, external review, lab tests and field tests.

This phase could be compared to TRL<sub>3-7</sub> in terms of;

TRL<sub>3</sub>: active R&D is initiated. This includes analytical studies, laboratory studies and physically validating analytical predictions of separate elements of the technology.

TRL<sub>4</sub>: Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in the laboratory.

System concepts that have been considered and results from testing laboratory-scale breadboard(s). Provide an estimate of how breadboard hardware and test results differ from the expected system goals.

TRL<sub>5</sub>: The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include "high-fidelity" laboratory integration of components. Results from testing laboratory breadboard system are integrated with other supporting elements in a simulated operational environment.

Questions asked: How does the "relevant environment" differ from the expected operational environment? How do the test results compare with expectations? What problems, if any, were encountered? Was the breadboard system refined to more nearly match the expected system goals?

TRL<sub>6</sub>: Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.

Questions asked: How did the test environment differ from the operational environment? Who performed the tests? How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before moving to the next level? TRL<sub>7</sub>: Prototype near or at planned operational system. This level represents a major step up from TRL 6 by requiring demonstration of an actual system prototype in an operational environment (e.g., in an air-craft, in a vehicle, or in space).

Results from testing a prototype system in an operational environment, Same Questions as at TRL 6

### 3.4. Limitations

TRA<sub>c</sub> and TRL 8-9 will be up to the companies within the research project to finalize and will not be done in the project itself, therefore it will not be brought up in this paper.

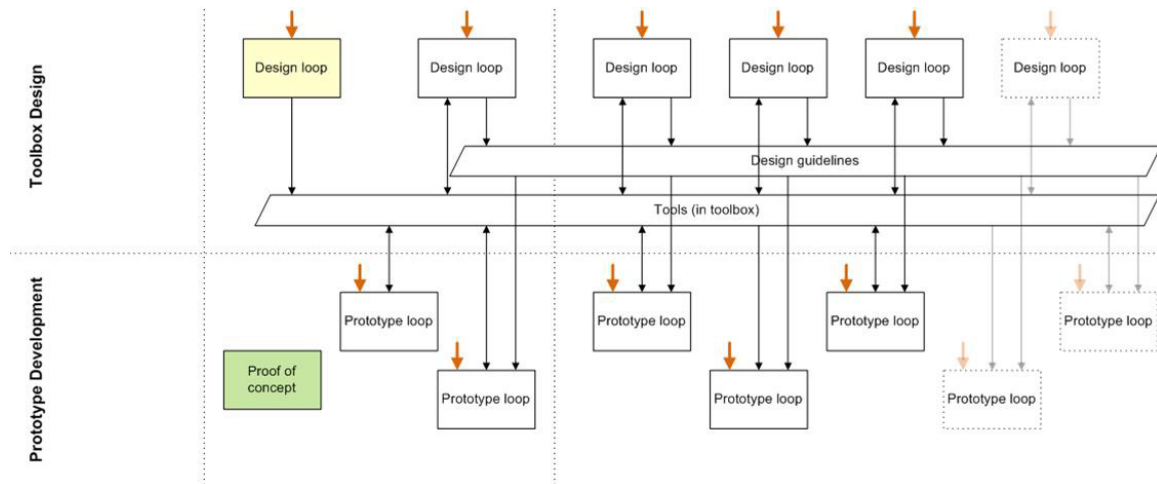


Fig. 3 Step 2 and 3 in the PDP

### 3.5. Tool development for the Toolbox

The tools that should be tested for prototyping were collected through a three-step analysis, using the needs from all the seven participating companies. 1) Division into themes (or common needs) 2) Judgment criteria i.e. factors that justifies prototyping and 3) Weighting and summarizing the themes and judgment criteria, creating design tools for further prototyping [24].

Seven design tools were listed (weighted) as the most important tools:

1. Work instructions
2. Tagged checkpoints
3. Dynamic work tasks
4. Remote real time monitoring
5. Real time communications
6. Share information
7. Filter information

One or many of these tools are then chosen to be developed and tested in laboratory or production environment.

### 3.6. Prototype development

The design tools were then turned into prototypes due to the company's needs. A total of five prototypes have been developed with different evaluation types. Table 2 shows the prototypes connected to the design tools and the evaluation.

Table 2. Prototypes

Prototypes	Connection to the design parameters	Evaluation
Prototype A	Tagged checkpoint	Internal review, small Field tests
Prototype B	Dynamic Work tasks	Field tests
Prototype C	Shop floor twitter	Internal review
Prototype D	"The hard ware case"	Field tests
Prototype E	Work Instructions	Internal review, small Field tests

The following sections will give examples from the two case companies regarding TRL levels and how the design tools have been developed into prototypes.

### 3.7. Case A – Current TRL = 2-3 (DesignBox-loop), Design parameter 7 and Prototype E

This case is at TRL<sub>2</sub> i.e. based on that the invention of solutions begins and practical application could be invented and TRA<sub>b</sub> i.e. (b) the point for a decision from several competing design options:

Today the order-handling and instructions are paper-based and follows the product batches on special-made wagons. There are information for all the stations in the pale so all the papers (15-20 papers per batch) are not needed everywhere. The communication between the operators is done thru telephone calls and mouth-to-mouth or short meetings. In order to decrease the number of papers printed and to make the order handling more effective, the design



tools chosen for this case is: work instruction, share information. The technology chosen is electronic information and most likely mobile devices. TRL<sub>3</sub> is planned to start in February 2013 i.e. laboratory studies and small field tests, to physically validate the analytical predictions of separate elements of the technology and design tools.

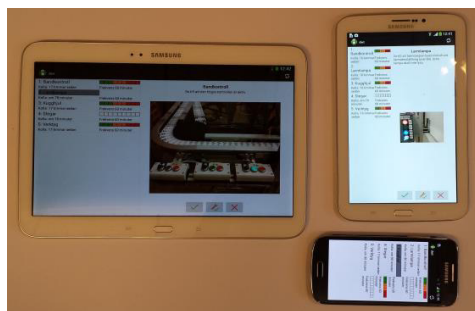
### 3.8. Prototype-loop Case B– Current TRL =6-7 (Prototype-loop, proof of concept), Prototype B and Prototype D

Case B are at TRL<sub>6-7</sub> and in the prototype loop i.e. the first field tests has been done

*TRL 6 - Laboratory tests and internal review: How did the test environment differ from the operational environment? Who performed the tests?* The project-teams' office environment was used as a laboratory environment. A list was created to form the equivalence of factory checkpoint tasks. Several people within the project team then tested the prototype. Feedback to the next prototype loop was given in the form of a workshop.

*How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before moving to the next level?* The physical difference between this simple laboratory setup compared to the real target environment was significant. This however was not obvious to the team during testing at this level. Therefore the feedback was perhaps too focused on insignificant details about the user interface. The level of feedback also became an unnecessary debate because the process had yet to define how to organize some of the data.

*TRL7 - Industrial tests:* After assessing the feedback from the first test the prototype was improved. Improvements were almost only related to user interface since this would be the focus for this second test. The targeted process factory case already had a checklist for daily rounds on paper. This information was copied, without any changes, into the prototype. The information, which consisted of text instructions and low-resolution images, was deliberately not improved in any way. The prototype software could handle different screen sizes. Three different sizes were used during



this test, 10, 7 and 4.3-inch screens, seen in figure 4.

Fig. 4. Prototype D: The hardware test

The target group of the end product, that is the operators at this specific process line, was the testers this time. The

testers were interviewed about their everyday experience regarding ICT tools. They then tested walking the daily round, which they all knew, with one of the three prototypes. Feedback came from observations of how the tester acted with the prototype. The tester also answered some questions and gave direct feedback after the test. That the opportunity to test a prototype in the targeted environment is important became apparent. Ex. the first test gave no input of how to account for greasy physical work tasks between usages of the tool. Perhaps surprisingly, no feedback suggested a different approach of how to visualize the information. And the team already knew most suggestions regarding user interface changes. Instead the size of tool to use was a hot topic.

## 4. Discussion

In order to use the TRL in a manufacturing context, it has to be adapted as said in the beginning there are some pros and cons with the methodology. It is always complex when designing tools for humans due to the differences in competence, willingness to try new technologies, maturity in the organization etc. The terms of TRL could and should be used when developing and designing ICT tools for operators, but in a broader way than used before:

### 4.1. Technology

The recent advances in information technologies have helped organizations to apply such technologies in innovative ways for supporting collaborative work practices. Such work practices represent a complex blend of human actors and technological systems, where individuals can accomplish tasks and interactions through technological systems that they could not otherwise achieve [8]. Despite this, very little attention has been paid to propose methods for evaluating technological maturity consistently between organisations [9]. New external technologies often need further development. By considering and especially integrating company external technologies in the existing production environment significant research and development efforts arise. Here, the company has to contemplate organizational as well as technical properties and requirements of the technology. [10].

### 4.2. Readiness

In line with [10, 21] the technology maturity should also be integrated into the evaluation process, this could be described as a readiness to use and develop new technology. Building up the know-how can be very time-consuming and expensive, therefore, the decision of eliminating an established technology or following up a new one is crucial [10]. The developer has to take the back-end system into consideration when designing tools for manufacturing industries, the information structure is often much more complex than to do a front-end stand-alone system [25]. This is of course a good start to show the technology and to do

small field tests, but in order to reach TRL=9 companies have to consider the information structure behind.

#### 4.3. Levels

The tools should be design in order to suit different Levels of Competences [26] and the Levels of Cognitive Automation should also be considered so that the companies doesn't over automate just because it is a new technology, it is a thin line between over automating and being ground breaking

#### 5. Conclusion

This paper has shown that it is possible to use the methodology of TRA and TRL in order to design ICT-tools in a production context. These methods and levels are used as part or guidelines to evaluate the different technologies in a more structured way and to assure high quality of the investigation when developing ICT-tools. Because of the complexity in the product, organization and operator herself it is hard to justify an implementation solely based on technology. The technology is a helping tool in order to reach other goals, not a goal itself.

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